MOVEMENTS AND SURVIVAL OF FLEDGLING COOPER'S HAWKS IN AN URBAN ENVIRONMENT

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Abstract.– Cooper's hawks (*Accipiter cooperii*) nest in urban and suburban areas in several places across North America, but little is known about the movements, habitat use, or survival of their fledglings. We followed 40 radio-tagged Cooper's hawks hatched in Tucson, Arizona in 1999 or 2000 for up to 6 months after fledging to estimate their survival, and determine how far they disperse from natal sites, the kinds of environments they use while dispersing, and the characteristics of areas they use when they settle during their first winter. The typical pattern of movement for hawks we were able to track through early winter consisted of sedentary behavior in the natal area, followed by relatively long movements beginning 11-13 weeks after hatching, and finally sedentary behavior again when they settled into a winter home range. Distances between locations were, on average, greater for females ($\bar{x}$ = 6,814 m, range = 16-51,673 m, SD = 9,752) than males ($\bar{x}$ = 3,776 m, range = 46-20,759 m, SD = 5356) (*t*-test, $P = 0.02$). Home range size for 9 hawks during their first winter averaged 771 ha (SD = 403). Centers of home ranges from natal sites averaged nearly twice as far for females ($\bar{x}$ = 10.9 km, range = 4,160-19,500 m, SD = 387) as males ($\bar{x}$ = 6.0 km, range = 2,150-13,210, SD = 5.0), but the difference was not significant (*t*-test, $P = 0.23$). Survival of radio-tagged hawks was 67%. Hawks used a variety of environments during dispersal, but were found regularly (35% of locations) in riparian areas. We found no discernable pattern of habitat use for the land use categories inside winter home ranges. We speculate that the abundance of food may facilitate survival of dispersing hawks in the urban environment.

Natal dispersal in birds is the movement of fledglings away from their nests, and usually is measured as the distance between natal nests and sites where birds first breed, if they survive (Howard 1960, Greenwood and Harvey 1982). Distances traveled by dispersing birds and their survival can significantly affect genetic structure, demography, and viability of bird populations (e.g., Pulliam and Danielson 1991, Payne and Payne 1993). Survival and distances traveled during natal dispersal are, in turn, influenced by the kinds of environments through which dispersing individuals move (e.g., Miller et al. 1997). Information about environments that facilitate movement and survival during dispersal are, therefore, important in the development of habitat management plans for birds, especially if plans encompass broad spatial scales (e.g., Strong and Bancroft 1994, Miller et al. 1997) and fragmented landscapes (e.g., Temple 1989). Estimates of survival during the first year of life (or portions thereof) also are important variables in models of population growth and viability (Lande 1988, Boyce 1992, Beissinger and Westphal 1998).

Dispersal has been studied in a variety of bird species over the last decade, but information about it remains limited compared to other aspects of population demography and other kinds of movements (Koenig et al. 2000, Walters 2000). Among birds of prey, dispersal has been studied primarily in species that are the focus of management and conservation efforts and in environments that are relatively undeveloped (e.g., Ferrer 1993, Woodbridge et al. 1995, Miller et al. 1997, Ganey et al. 1998, Harmata et al. 1999, Lehman et al. 2000, Restani and Mattox 2000). Cooper's hawks (*Accipiter cooperii*) nest in highly developed environments (i.e., urban and suburban areas) in several places across North America (see Rosenfield and Bielefeldt 1993 for review, Stewart et al. 1996, Boal and Mannan 1998, 1999), but little is known about movements, habitat use, or survival of their fledglings. Existing information suggests that Cooper's hawks may move up to 100 km from their natal nests in their first fall and winter, but movements during this period usually are <15 km (Rosenfield and Bielefeldt 1992, Boal and Mannan 1996). Thus, Cooper's hawks hatched in a relatively large metropolitan area could remain within developed environments during dispersal.

Knowledge of the patterns of movement and habitat use of dispersing Cooper's hawks in urban settings could be used to identify environments to protect or enhance as cities grow, assuming that hawk populations are a desired feature of the urban landscape. Furthermore, Boal and Mannan (1999) suggested that models of population growth of urban Cooper's hawks are needed to understand whether urban areas represent "sources" or "sinks" (Pulliam 1988) for this species. Estimates of survival of hawks during dispersal are critical to such modeling efforts. We followed Cooper's hawks hatched in an urban setting for up to 6 months after fledging to: 1) determine how far Cooper's hawks disperse from natal sites, the kinds of environments they use while dispersing, and the characteristics of areas they use when they settle during their first winter; and 2) estimate survival of fledgling Cooper's hawks from late summer through winter.

STUDY AREA

We marked and tracked fledgling Cooper's hawks in and near Tucson, Arizona (32 N, 111W). The Tucson metropolitan area encompasses about 70,000 ha with an estimated human population of 803,600 residents. Tucson includes developments ranging from commercial districts and high density housing to suburban areas with low density housing. Parks, golf courses, and open space are scattered throughout residential areas. Tucson is located in the Sonoran Desert and supports remnants of lower and upper Sonoran vegetation types and riparian corridors (Brown et al. 1979), but much of the natural vegetation has been removed or replaced with non-native plants.

METHODS

We used bal-chatri traps (Bloom 1987) to capture fledgling Cooper's hawks at nests monitored in a long-term study (Boal and Mannan 1999, Mannan and Boal 2000). We captured fledglings when they were old enough to hunt on their own and when their retrices were fully emerged (≥55 days old). We marked each captured fledgling with a U.S. Fish and Wildlife Service leg band and a colored leg band with a unique alpha code, and attached a radio-transmitter (model RI-2C [5 g] in 1999 and model PD-2 [3.5 g] in 2000; Holohil Systems Ltd.) to a central retrix (Samuel and Fuller 1994). Estimated life of transmitters was 6 months (model PD-2) or 9 months (model RI-2C). No more than 2 fledglings (usually a male and female) from any nest were radio-tagged.

We relocated radio-tagged hawks, while they remained in their nest areas, at least once/week by "homing" (White and Garrott 1990) with Teleonics TR-2 receivers and RA-14 flexible, two-element, yagi antennas. After hawks left their nest areas, we attempted to relocate them by scanning for their radio signals from 40 elevated positions (e.g., hillsides, tops of buildings) once or twice/week. Elevated positions were scattered throughout most of the Tucson metropolitan area so that any radio-tagged hawk present would likely be detected. If a signal was detected from an elevated position, we estimated its general location based on signal strength, and then attempted to locate the hawk by "homing" in an automobile and on foot. In areas without elevated positions, we drove along parallel roads throughout the area and scanned for radio signals. If a hawk settled into a relatively small area where it could be found with consistency (i.e., it established a home range), we attempted to relocate it up to 5 times/week at various times of the day by homing. We allowed at least 12 hr between relocations for any given hawk to minimize the risk of dependency among locations.

Once or twice/month, we flew in a single engine aircraft in parallel transects over the Tucson metropolitan area and scanned for radio signals. We also scanned for radio-tagged hawks while the aircraft was flown along major watercourses up to 100 km from Tucson. If a signal from a radio-tagged hawk was detected from the aircraft, we recorded the general area of the detection, and returned to the area in an automobile to search for the hawk.

Cooper's hawks in Tucson are acclimated to the presence of humans, and single observers can approach hawks without frightening them (Mannan and Boal 2000). Therefore, we attempted to see the hawks at each relocation. Sometimes hawks were out of sight (e.g., in a fenced back yard), but were close enough that their radio signal could be detected with the receiver connected only to the antenna cable (i.e., with the antenna detached). In such cases, we estimated the location of the hawk to be within 30 m of the strongest signal. If a hawk was out-of-sight, in an area where we did not have permission to visit, and not within 30 m of the observer, we estimated its position by triangulation. We marked all locations on an atlas of city streets.

Analyses

We plotted all locations of hawks on a digital coverage of the streets and land use categories in Tucson (Shaw et al. 1996). We first measured distances between all consecutive locations of hawks, including locations estimated from aircraft and elevated positions (i.e., in instances where we could not locate hawks by homing). If hawks established home ranges during fall and winter, we used the convex polygon method to generate area-observation curves (Odum and Kuenzler 1955) for each home range to assess whether our sample of locations adequately described home range size for the period of interest. We then estimated home range sizes with the kernal method (90% isopleth; Worton 1989). We applied a smoothing technique to the boundaries of home ranges based on least squares cross validation (h). We first calculated h for the set of locations for each hawk. We then estimated size of home ranges, and applied the average h to all home ranges (Kenward 2001). We only used locations of hawks identified by sight or triangulation, and those estimated to be within 30 m of the observer to calculate home ranges. We used programs RANGES V (Kenward and Hoddler 1996) and Arcview Version 3.2 to measure distances between locations and generate area-observation curves, and Arcview with the extension "Animal Movements" to calculate home ranges.

We assessed characteristics of home ranges by first overlaying outlines of the home ranges on the digital database of land use categories in Tucson (Shaw et al. 1996). We calculated the coverage of each category in each home range, compared the coverages to land use patterns shown on aerial photographs taken in 2001 to assess accuracy, and made minor corrections in two home ranges. We examined habitat selection of each hawk inside its home range by comparing the observed proportion of locations in each category to the proportion that would be expected if a hawk moved randomly inside its home range. All comparisons of observed and expected proportions were made with X^2 goodness-of-fit tests (Sokal and Rohlf 1995). We used the Kaplan Meier (1958) method to estimate survival of radio-tagged hawks. We conducted all statistical analyses in the JMP IN 3 Windows Version statistical package (Sall and Lehman 1996).

RESULTS

We radio-tagged 21 hawks in 1999 (10 females and 11 males), and 19 hawks in 2000 (8 females and 11 males). We relocated these 40 hawks a total of 527 times (58.3% by sight, 22.0% with the antenna detached from the receiver in combination with triangulation, 7.4% by triangulation alone, 7.4% from elevated positions, and 4.9% from aircraft). Six hawks (2 females and 4 males) lost the tail feather on which the radio was attached, and 5 (3 females and 2 males) died before meaningful information could be collected. Of the remaining 29 radio-tagged hawks, 19 (8 females and 11 males) either were located sporadically (i.e., $\leq$9 times) throughout the fall, or early in the fall but never again, and 10 (5 females and 5 males) remained within 20 km of the Tucson metropolitan area at least into late October.

Movements

The typical pattern of movements for hawks we were able to track through early winter consisted of sedentary behavior (i.e., short inter-location distances) in the natal area, followed by relatively long movements beginning 11-13 weeks after hatching, and finally by sedentary behavior again when hawks established a fall/winter home range (Fig. 1). Inter-location distances were, on average, greater for females ($\bar{x}$ = 6,814 m, range = 16-51,673 m, SD = 9,752) than males ($\bar{x}$ = 3776 m, range = 46-20,759, SD = 5356) (*t*-test, $P = 0.02$) (Fig. 1). One female, for example, made 2 movements of >59 km in a period of <20 days. However, neither males nor females moved in discernable patterns after they left their natal areas, and generally we found hawks of both sexes in scattered locations throughout Tucson before they settled for the fall/winter (Fig. 2).

We obtained sufficient relocations on 9 of 10 hawks to estimate size of home range during the fall/winter (Table 1). Seven of the 9 home ranges had stablized in area by the end of our sampling period (≤5.1% increase in area over at least the last week of sampling), but home ranges of two females were still increasing (8.8 and 13.2%) when the hawk died or the radio failed (Table 1). Home range size for the 9 hawks averaged 771 ha (SD = 403), and did not differ (*t*-test, $P = 0.80$) between males ($\bar{x} = 804$ ha, SD = 456) and females ($\bar{x} = 731$, SD = 387) (Table 1). Centers of home ranges from natal sites were nearly twice as far for females ($\bar{x}$ =10.9 km, range = 4,160-19,500 m, SD = 6.4) as males ($\bar{x} = 6.0$ km, range = 2,150-13,310 m, SD = 5.0]), but the difference was not significant (*t*-test; $P = 0.23$). Eight of 9 home ranges encompassed 1 or 2 traditional nest sites of Cooper's hawks, but none of the dispersing hawks incorporated their natal nest sites in their fall/winter ranges.

Habitat Use

We found hawks in a variety of environments after they left their natal areas and before they settled into winter home ranges; environments used included riparian areas (35%), high density (≥7.4 residences/ha) residential areas (25%), low density (<7.4 residences/ha) residential areas (22.5%), and parks and golf courses (17.5%) ($n = 40$ locations for all hawks combined, excluding those estimated from aircraft and elevated positions). Once hawks settled, their home ranges also varied in composition. Some encompassed mostly high density residential areas, others encompassed mostly low density residential areas, and others were dominated by cemeteries, neighborhood parks and natural open space, or golf courses and district and regional parks (Table 2). We found no discernable pattern of habitat use for land use categories inside home ranges. Only 3 of the 9 hawks showed significant levels of selection for the categories we examined and, although all 3 of these hawks avoided commercial areas and roadways, there was no consistent pattern of use among the other categories (Table 2).

Survival

Survival of radio-tagged hawks through 180 days was 67%. Two males and 4 females died while we were tracking them, but there was no difference in survival (Wilcoxon test, P = 0.66) between males (75%) and females (64%). Of the 6 hawks that died, 2 females were killed by collisions with cars, 1 male was electrocuted, and 3 died of unknown causes.

DISCUSSION

Movements and Habitat Use

The wide-ranging movements we detected among fledgling Cooper's hawks between 11 and 22 weeks after hatching are similar to those observed in related species (e.g., sparrowhawks [*Accipiter nisus*] in southern Scotland [Newton 1986:261]), and presumably were explorations in search of a place to settle for the winter. Initiation of "exploratory" movements may be triggered by a reduction in the amount of food provided by parents in the natal area. Environmental and social cues that triggered Cooper's hawks to settle for the winter are unknown, but rich sources of food (e.g., concentrations of birds at bird feeders), and low levels of intra- and interspecific competition are likely candidates. A variety of environments were used by hawks during the "exploration" period. We did not have a data base identifying land use on the entire area used by dispersing hawks, but riparian systems were used by hawks (35%) more than they generally occur on the landscape (e.g., 6% in the Tucson metropolitan area, Shaw et al. 1996), suggesting that riparian corridors may be attractive to dispersing hawks as sources of food and cover, or facilitate their movements in the urban environment.

Females disperse farther than males in many species of birds (Greenwood and Harvey 1982). We found that females moved greater distances between locations than males, especially from 11-22 weeks after hatching. The wide-ranging movements of females may result in them settling farther from their natal nests than males, but our small sample of winter home ranges and the restricted area in which we were able to follow hawks precluded definitive assessment of this relationship. The movements of hawks we report herein also may be biased in that some of the hawks we could not locate may have moved farther than those we were able to track. It is also possible that some of the hawks we located only sporadically throughout the fall never established a home range.

Home ranges of Cooper's hawks in Tucson during their first winter were, on average, 11 times larger than the home ranges of breeding males (Mannan and Boal 2000), and typically overlapped 1 or 2 traditional breeding ranges. We do not know whether the home ranges established in the first fall/winter of life persist into the following breeding season and beyond, but 2 male hawks radio-tagged in 1999 nested, or attempted to nest, 2 years later in sites that were encompassed their first winter home ranges. A female hawk, radio-tagged in 2000, nested 2 years later in a site that was 4.6 km from the edge of her first winter home range. Apparently, some hawks stay in the home ranges they establish in their first winter until an opportunity for nesting arises, whereas others search outside these ranges for breeding sites.

Home ranges of the hawks we tracked were dominated by a variety of land use categories, and no consistent pattern of use by hawks was evident among categories within home ranges. We speculate that habitat use by Cooper's hawks during their first winter varied relative to the land use categories we examined because rich sources of food (i.e., concentrations of birds) could be found in a variety of urban environments (Germaine et al. 1998).

Survival

Survival of birds of prey during dispersal is low for many species (e.g., Belthoff and Richison 1989, Rohner and Hunter 1996, Ganey et al. 1998, but see Harmata et al. 1999) probably because fledglings are relatively inexperienced in acquiring food and avoiding predators and other agents of mortality. We found survival to be relatively high among Cooper's hawks in Tucson for 6 months after fledging. Abundance of food can influence survival of dispersing birds (e.g., Rohner and Hunter 1996), and we speculate that an abundance of prey in Tucson may reduce mortality associated with lack of food sufficiently to offset agents of mortality common in developed environments (e.g., collisions with vehicles and windows, electrocution). Our speculation that Tucson provides ample food for Cooper's hawks is supported by evidence that total density and biomass of birds is higher in urban than non-urban areas (e.g., in Tucson, Emlen 1974; elsewhere, Beissinger and Osborne 1982, Blair 1996, Marzluff et al. 1998).

Boal (1997) modeled the dynamics of the population of Cooper's hawks in Tucson, Arizona and concluded that the population was declining at about 8% per year (lambda = 0.92), primarily due to mortality of nestling/fledglings from trichomoniasis (Boal and Mannan 1999). He noted, however, that his estimate of survival of hawks between fledging and 1 year of age (i.e., juvenile hawks) was the primary limitation and weakness in the model. Boal (1997) estimated survival of juvenile hawks to be 0.19% based on mark-recapture analyses, but recognized that the estimate was likely biased because of low recapture rates. Boal (1997) concluded that for the population of Cooper's hawks in Tucson to be stable or increasing, survival of juvenile hawks would have to be ≥29%. Our estimate of survival of juvenile hawks for 6 months was 67%. Juvenile survival over the first year can then be roughly estimated to be 45% (0.67x0.67), assuming survival is similar throughout the first year. If productivity, mortality from trichomoniasis, and survival of breeding individuals is similar in Cooper's hawks between 1994-1997 and 1998-2001, then the Tucson Metropolitan area is not a sink for Cooper's hawks.

Future Research and Assessment of Methodology

One weakness in this study was that we could not follow the movements of nearly half of the hawks on which we attached radio-transmitters. Possible explanations for this problem are: 1) the radios on these hawks failed; 2) our searches within the defined study area were inefficient; or 3) the hawks moved beyond the area we searched. We suspect that the last explanation (i.e., hawks moved out of the study area) is the most likely. Satellite transmitters have been used to track wide-ranging movements in other species of hawks and eagles, but the smallest models of satellite transmitters are still too large for Cooper's hawks to carry. Scanning for radio signals more frequently and over a wider area from aircraft currently is the best solution to this problem.

The inability to track hawks throughout their first year of life was another weakness of the study. Estimates of survival based on tracking hawks for longer periods would be more reliable, but require use of heavier transmitters. Cooper's hawks can carry transmitters larger than the ones we employed, but they require attachment with a backpack harnesses (Kenward 2001). We chose to attach our transmitters to tail feathers, despite the possibility of premature molts, to reduce the chance of having a hawk become entangled and die. We felt that the potential consequences of having a study animal die from our research activities in an urban environment dictated that we reduce the risk of death as much as possible. However, if estimates of survival for juvenile hawks are to be empirically derived, backpack harnesses may need to be employed.

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Table 1. Size of home ranges during fall/winter for fledgling Cooper's hawks in Tucson, Arizona 1999 or 2000.

Hawk ID[a]	Period tracked in home range	n^b	Percent increase[c]	Distance to nest[d] (km)	Area (ha)
m327	9/16/99-2/18/00	20	4.3	2.2	492
m457	9/12/00-12/2/00	32	3.6	9.1	537
m885	8/11/99-3/8/00	73	0.0	2.2	556
m854	8/16/99-10/26/99	13	5.1	3.1	854
m313	9/9/00-12/11/00	23	3.2	13.3	1580
f215	8/26/00-11/26/00	32	8.8	4.2	409
f977	7/22/99-2/15/00	63	0.0	10.8	593
f276	9/23/00-12/3/00	30	13.2	9.2	628
f259	8/14/00-11/13/00	16	0.0	19.5	1294

[a]m=males; f=females.

[b]Number of relocations

[c]Increase in area in the home range over at least the last week of sampling, representing at most the five locations.

[d]Distance from center of the winter home range to natal nest.

Table 2. Percentages of locations within 5 land use categories[a] in home ranges of fledgling Cooper's hawks during their first fall/winter in Tucson, Arizona, 1999 or 2000.

	Percent of locations (percent of home range)					
Hawk ID[b]	Low residential	High residential	Low use	High use	Other	P^c
m327	0.0 (6.1)	60.0 (51.4)	15.0 (21.5)	10.0 (11.7)	15.0 (0.09)	0.52
m457	78.6 (58.5)	3.6 (12.5)	7.1 (16.7)	0.0 (1.2)	10.7 (11.1)	0.13
m885	0.0 (6.6)	78.6 (52.8)	12.9 (17.2)	0.0 (1.8)	8.5 (21.3)	<0.0001
m854	46.1 (37.4)	7.6 (13.4)	38.5 (33.5)	0.0 (4.8)	7.7 (10.8)	0.73
m313	16.7 (7.4)	45.8 (24.3)	29.2 (37.6)	0.0 (1.2)	8.3 (19.6)	0.14
f215	36.7 (12.9)	13.3 (28.2)	3.3 (6.6)	46.7 (37.7)	0.0 (14.7)	<0.001
f977	81.4 (72.1)	0.0 (3.3)	10.2 (18.4)	8.5 (5.0)	0.0 (1.0)	0.19
f276	0.0 (0.0)	50.0 (54.3)	19.2 (17.8)	26.9 (2.4)	3.8 (25.5)	<0.0001
f259	25.0 (24.7)	31.2 (24.9)	31.2 (39.7)	6.3 (6.4)	6.3 (4.3)	0.95

[a]Low residential <7.4 residences/ha; High residential $\geq$7.4 residences/ha; Low use = cemeteries, neighborhood parks and natural open space; High use = golf courses, district and regional parks, and schools, and Other = roadways, and commercial, industrial, and agricultural areas.

[b]m=males; f=females.

[c]*P* values are from chi-square goodness-of-fit tests (Sokal and Rohlf 1995). Categories with zero values were lumped to meet assumptions of the tests.

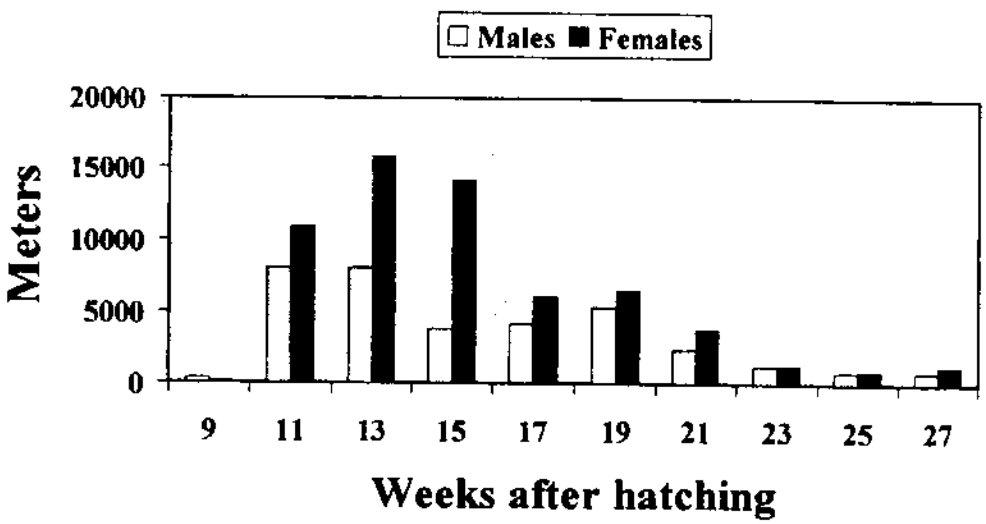

Figure 1. Average distance between locations in two-week periods for radio-tagged Cooper's hawks after fledging from nests in Tucson, Arizona, 1999 or 2000 (n = 4-17 for males, and 4-13 for females, depending on period; mean number of days between locations from 11-22 weeks after hatching was similar for males [6.7, SD = 5.2] and females [7.6, SD = 7.4] [t-test, P = .38]).

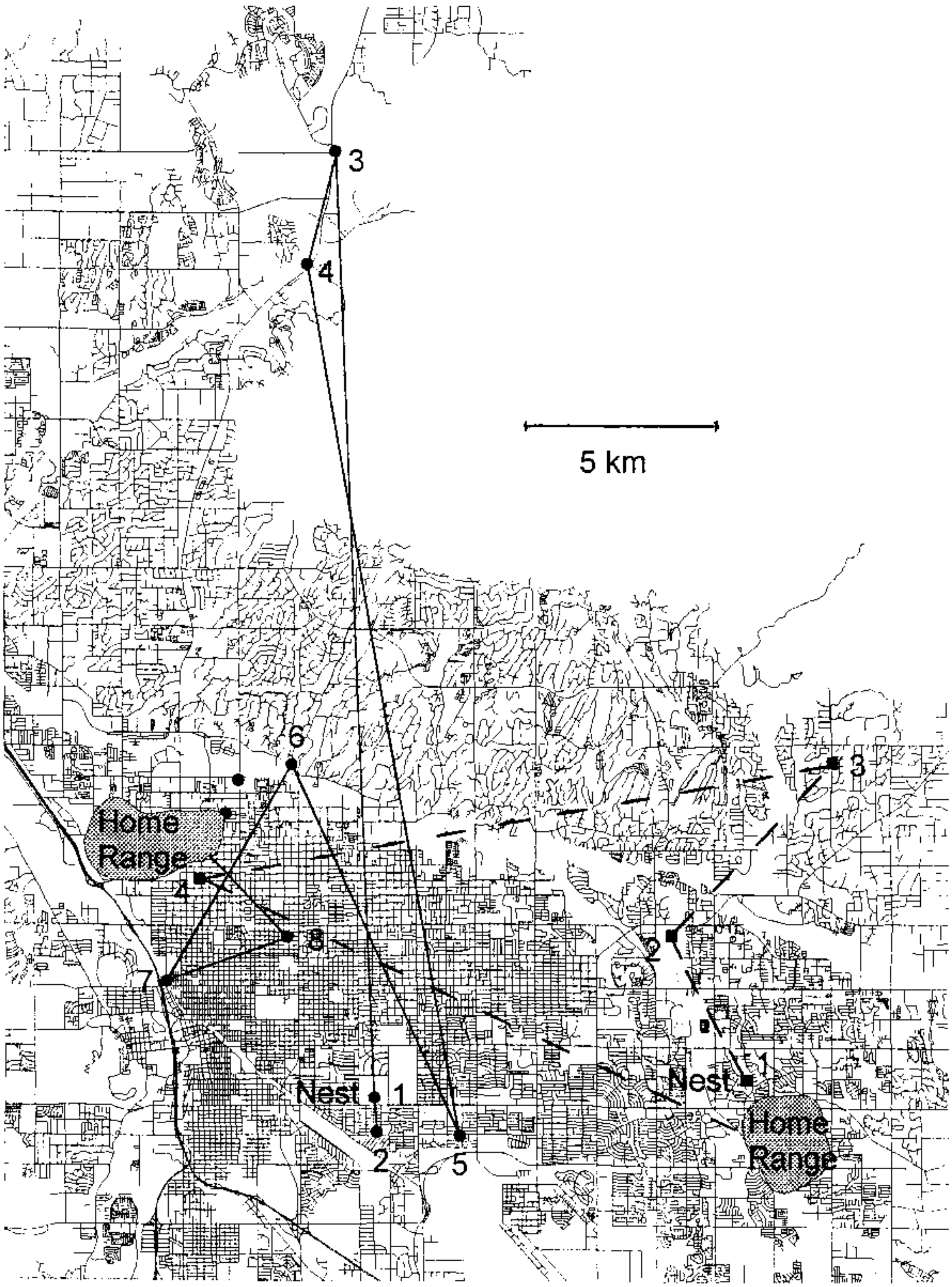

Figure 2. Movements of two hawks (female = solid line; male = dashed line) between leaving their natal area and settling into a fall/winter home range in Tucson, Arizona, 1999 or 2000. Multiple locations in the natal area are represented by a single location.